Flour Mill Stream Blending Affects Sugar Snap Cookie and Japanese Sponge Cake Quality and Oxidative Cross-Linking Potential of Soft White Wheat

Daniel D. Ramseyer, Arthur D. Bettge, and Craig F. Morris

Abstract: The purpose of this research was to study the functional differences between straight grade (75% extraction rate) and patent (60% extraction rate) flour blends from 28 genetically pure soft white and club wheat grain lots, as evidenced by variation in sugar snap cookie and Japanese sponge cake quality. Functional differences were examined relative to arabinoxylan content, protein content, and oxidative cross-linking potential of flour slurries. Oxidative cross-linking measurements were obtained on flour slurries with a low shear Bostwick consistometer and considered endogenous oxidative cross-linking potential (water alone) or enhanced oxidative cross-linking potential (with added hydrogen peroxide-peroxidase). A 2-way ANOVA indicated that flour blend was the greater source of variation compared to grain lot for all response variables except water-extractable arabinoxylan content. Patent flours produced larger sugar snap cookies and Japanese sponge cakes, and contained significantly less total and water-unextractable arabinoxylans, protein, and ash than did straight grade flours. Patent flours produced more viscous slurries for endogenous and enhanced cross-linking measurements compared to the straight grade flours. The functional differences between patent and straight grade flours appear to be related to the particular mill streams that were utilized in the formulation of the 2 flour blends and compositional differences among those streams.

Keywords: arabinoxylans, cake, cookie, milling, wheat

Introduction

Physicochemical tests are commonly used to evaluate and/or predict the end-use attributes of wheat flour. Tests such as sodium dodecyl sulfate (SDS)-sedimentation, mixograph, and solvent retention capacity (SRC) produce quick results and are conducive to high throughput. However, it is generally considered more reliable to assess the end-use quality of wheat (*Triticum aestivum* L.) varieties and grain lots through predictive bake tests. Production of a model food product (pan bread, cookies, pancakes, noodles, crackers, and so on) as an estimation of end-use quality is considered to be a more "true" assessment of functionality of the flour. Two bake tests which are routinely used to evaluate soft white and club wheat quality are sugar snap cookies and Japanese sponge cakes (Morris and Rose 1996).

Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by the USDA implies no approval of the product to the exclusion of other that may also be suitable. This article is in the public domain and not copyrightable. It may be freely reprinted with customary crediting of the source.

Identifying factors that affect variation in sugar snap cookie and Japanese sponge cake quality is important in order to produce more consistent and higher quality products. Sugar snap cookie quality is affected by factors such as starch damage (Gaines and others 1988; Hoseney and Rogers 1994; Donelson and Gaines 1998; Barrera and others 2007; Pareyt and Delcour 2008), protein (Donelson 1988; Gaines 1990; Kaldy and others 1993; Miller and Hoseney 1997; Bettge and Morris 2007; Pareyt and Delcour 2008), and arabinoxylan content (Bettge and Morris 2000, 2007; Pareyt and Delcour 2008). The AACC Intl. sugar snap cookie method (10–52) is considered to be most relevant to the prediction of low moisture soft wheat products. Alternatively, Japanese sponge cakes are used to assess the suitability of soft white and club wheat flours for high moisture cake products consumed in the Pacific-Asian market. The variation in quality of Japanese sponge cakes is largely due to starch characteristics (Nishio and others 2009; Nakamura and others 2010) and may be partially related to batter viscosity (Gaines and Donelson 1982).

Arabinoxylans may exert an influence on the quality of sugar snap cookies and Japanese sponge cakes in several ways: effects on viscosity and water relations, and through the formation of oxidative gels, which result from covalent cross-linking. Arabinoxylans are nonstarch polysaccharides that consist of a β-1, 4 xylose backbone with arabinose residues branching from the 2- and/or 3-carbon position. The arabinose substitution pattern along the xylose backbone affects the water extractability of the polymers. That is, total arabinoxylan (TAX) content can be empirically subdivided into water-extractable arabinoxylan (WEAX) and water-unextractable arabinoxylan (WUAX) frac-

tions. WEAX have unlinked ferulic acid residues esterfied at the C (O)-5-position on a varying number of arabinose branches. In the presence of enzymatically or chemically produced free radicals, oxidative cross-linking among unlinked ferulic acid residues occurs to produce a large, interconnected network of arabinoxylan polymers (Morita and others 1974; Neukom and Markwalder 1978; Vinkx and others 1991; Niño-Medina and others 2010). Oxidative cross-linking can also occur between tyrosine residues on protein polymers and between WEAX and protein through ferulic acid-tyrosine dimerization (Neukom and Markwalder 1978; Oudgenoeg and others 2001; Wang and others 2002).

Currently, the capacity of different mill streams to form oxidative cross-links and thus influence flour stream blending and end-use quality is not well established. The effect of flour blends for Asian noodle quality (Kruger and others 1994; Hatcher and Symons 2000; Ye and others 2009) as well as for bread and tortilla quality has been reported (Ambalamaatil and others 2002). However, the noodle research focused more on the effect of flour blends on noodle discoloration characteristics, and the bread and tortilla research did not address the oxidative cross-linking potential of flour blends. Furthermore, there is limited information available on the effect of flour blending on the end-use quality attributes of soft white and club wheat products such as sugar snap cookie or Japanese sponge cake. Gaines (1985) examined the effect of flour blends on sugar snap cookie spread, but the research focused more on the effect of particles size on end-use quality attributes. Research on flour blends and cake volume do not specifically address Japanese sponge cakes and are also primarily focused on the effect of particle size on end-use quality (Chaudhary and others 1981; Gaines 1985).

It is of interest to identify sources of variation in flour blends and the effects on end-use quality. Therefore, the purpose of this research was to establish the effect of mill stream blending for soft and club wheat varieties on TAX, WUAX, and WEAX content as well as the oxidative cross-linking potential of straight grade and patent flours.

Materials and Methods

Wheat samples

Twenty-eight genetically pure grain lots representing advanced wheat lines and commercial cultivars common to the western United States and harvested in the 2008, 2009, and 2010 crop years were obtained from the U.S. Dept. of Agriculture, Agriculture Research Service Western Wheat Quality Laboratory in Pullman, Wash., and were included in the U.S. Wheat Associates Overseas Varietal Analysis Program. Grain lots represented soft white winter, soft white spring, and winter club cultivars, and were identified by the commercial name and crop year in which they were harvested. Nine grain lots were from the 2008 crop year: Bitterroot 2008, Stephens 2008a, Stephens 2008b, Stephens 2008c, Skiles 2008, ORCF102 2008, Eltan 2008, Louise 2008, and Cara 2008. Nine grain lots were from the 2009 crop year: Bitterroot 2009, Stephens 2009a, Stephens 2009b, Stephens 2009c, Skiles 2009, Cataldo 2009, ORCF102 2009, Eltan 2009, and Cara 2009. Ten grain lots were from the 2010 crop year: Bruneau 2010, Stephens 2010a, Stephens 2010b, Stephens 2010c, Eltan 2010, Cataldo 2010, ORCF103 2010, Skiles 2010, Xerpha 2010, and Cara 2010. The Stephens samples were originally derived from the same source; those designated with the same year were milled separately but during the same mill run, those with different year designations were milled during different years.

Milling

The 28 samples were milled on a Miag Multomat pilot mill. Grain was tempered to 14% or 16% moisture, soft and hard, respectively. All grain received an additional 0.5% temper immediately prior to milling. Grain was milled at a feed rate of 900 g/minute. This mill produced 10 flour streams: 1st Break, 2nd Break, Grader, 3rd Break, 1st Middlings, 1st Middlings redust, 2nd Middlings, 3rd Middlings, 4th Middlings, and 5th Middlings (Ramseyer and others 2011a). Straight grade flour was produced by blending all 10 flour streams together; the desired extraction rate was approximately 75%. Long patent flour was produced by blending 1st Break, 2nd Break, 1st Middlings, 1st Middlings redust, and 2nd Middlings; the desired extraction rate was approximately 60%. Flour streams were blended by first sifting through a rebolt sifter fitted with a 100-μm sieve and then thoroughly mixed to homogeneity in a 114-kg paddle blender (Duplex, Springfield, Ohio, U.S.A.).

Proximate analysis and starch damage

The 28 grain lot samples were analyzed in duplicate for protein, moisture, and ash. Moisture and ash were measured in a thermogravimetric oven (Leco TGA-601, Leco Corp., St. Joseph, Mich., U.S.A.). Protein (N × 5.7) was determined by the Dumas combustion method (AACC Intl. Approved Method 46-30, 2008) (model FP-528, Leco Corp.). Single kernel characterization system (SKCS) hardness on the parent grain lots was measured with the Perten SKCS 4100 (Perten Instruments, Springfield, Ill., U.S.A.). Percentage starch damage (expressed on an as-is basis) was determined using the AACC Intl. Approved Method 76-31 (2008).

Test baking

Cookie baking was performed and cookie diameter (cm) was measured using the AACC International Approved Method 10-52 (2008) for sugar-snap cookies. Minor modifications included increased $NaHCO_3$ (1.06% [w/v] in 'Solution A'), increased NH_4Cl (0.677% [w/v] in 'Solution B'), and decreased NaCl (0.261% [w/v] in 'Solution B'). Japanese sponge cake volume (cc) was measured using the method of Nagao and others (1976).

Arabinoxylan determination

Grain lot samples were analyzed for TAX and WEAX. A colorimetric method described by Douglas (1981) that measures pentose sugar content in wheat flour after hydrolysis was modified to measure TAX and WEAX from wheat flour (Finnie and others 2006). WUAX was calculated as the difference between TAX and WEAX. Arabinoxylan content was calculated as mg of xylose equivalents after conversion using a xylose standard curve and expressed as mg of xylose equivalents (Douglas 1981).

Bostwick viscosity determination

The viscosity of flour-water slurries was measured as flow distance with a modified method of Bettge and Morris (2007) which utilized a Bostwick consistometer (VWR International, West Chester, Pa., U.S.A.). Briefly, flour samples (10 g, 14% moisture content) were weighed into 50-mL conical screw-cap polypropylene tubes (nr 05-539-9, Fischer Scientific, Pittsburgh, Pa. or equivalent). Deionized water (25 mL) was added to hydrate the flour samples and the suspension was hydrated for 20 min on a laboratory rocker (AR-100, PGC Scientific, Gaithersburg, Md., U.S.A.) at room temperature (21 °C). At the end of

20 min, additional reagents were added, as appropriate, and the slurry was poured into the reservoir of a Bostwick consistometer. The reservoir gate was tripped after 2 min, allowing the reservoir to empty, and the distance the slurry flowed was measured after 40 s. All viscosity measurements were conducted at 21 °C and were replicated for each sample and treatment.

The treatment conditions used were (1) hydration with water (25 mL) for 20 min; (2) hydration with water (24.875 mL) for 20 min plus addition of 65 μL of 3% (v/v) hydrogen peroxide and 60 μL of horseradish peroxidase (1 purpurogallin unit μ/L). These treatment conditions provided the following analyses: (1) water, to measure the combined viscosity and endogenous oxidative cross-linking of WEAX and protein; (2) 3% hydrogen peroxide-horseradish peroxidase (POx), to measure the enhanced viscosity resulting from the oxidative cross-linking potential of WEAX and protein. Hydrogen peroxide (3% USP) was obtained from Fischer Scientific; horseradish peroxidase (Type I) was obtained from Sigma (St. Louis, Mo., U.S.A.), and dissolved in water to 1 U/μL, aliquotted and stored at −80 °C until immediately prior to use.

Statistical analysis

All statistical analyses were performed using PC-SAS statistical analysis software (v9.2, SAS Institute, Cary, N.C., U.S.A.). Primarily, a general linear model approach was used for ANOVA followed by Tukey's Honestly Significant Difference for testing mean differences. Type III sums of squares were reported.

Results and Discussion

Sources of variation and mean values for wheat flour constituents (TAX, WUAX, WEAX, protein, and ash) are summarized in Table 1. Sources of variation and mean values for end-use quality data (water viscosity, POx viscosity, starch damage, cookie diameter, and cake volume) are summarized in Table 2. The 2-way ANOVA models for all response variables were robust in that 88% to 99% of the total variation (R^2) was explained by the model (Table 1 and 2). The main effects were significant sources of variation ($P < 0.0001$) for all response variables except the flour blend effect for WEAX ($P = 0.17$). The flour blend effect was generally a greater source of variation (except WEAX) than was the grain lot effect. Among the response variables, the flour blend effect was between 2- and 60-fold greater than the grain lot effect.

There were significant differences between straight grade flour and patent flour for all response variables except for WEAX (Table 1). Straight grade flours had on average significantly more TAX, WUAX, WEAX, protein, and ash content, as well as a higher level of starch damage compared to patent flours. Straight grade flour slurries were less viscous than those of patent flours; straight grade flours also had smaller differences between the 2 viscosity measurements at 3.2 cm (average straight grade) compared with 3.4 cm (average patent), demonstrating that straight grade flours have reduced capacity for oxidative gelation than do patent flours, and this has implications for production of end-products.

The interactions between flour blend and variety were significant for WEAX, protein, and POx viscosity ($P < 0.0001$, Table 1 and 2). The interaction term for TAX, WUAX, ash, and water viscosity were not significant ($P > 0.01$). The interaction terms for cookie diameter and cake volume were not calculated since replicate measures were not available for these 2 response variables (Table 2). The contributions of the interactions to the overall ANOVA model were minor compared to the main effects for protein and POx viscosity. It is of interest to explore the interactions for WEAX as it may aid in better understanding the effect of grain lot on flour blends. Sixteen varietal grain lots (Bitterroot 2008, Bitterroot 2009, Bruneau 2010, Cara 2008, Cara 2009, Cara 2010, Eltan 2008, Eltan 2010, Louise 2008, ORCF102 2008, Skiles 2008, Skiles 2009, Stephens 2008b, Stephens 2008c, Stephens 2009a, and Stephens 2010a) had more WEAX in straight grade flours than in patent flours. Twelve varietal grain lots (Cataldo 2009, Cataldo 2010, Eltan 2009, ORCF102 2009, ORCF103 2010, Skiles 2010, Stephens 2008a, Stephens 2009b, Stephens 2009c, Stephens 2010b, Stephens 2010c, and Xerpha 2010) had more WEAX in patent flours than in straight grade flours. Indeed, this interaction is likely the reason why the flour blend effect was not significant for WEAX.

For the 2-way ANOVA models without interaction terms, cookie diameter and cake volume, flour blend was the greater source of variation. Straight grade flours produced on average

Table 1– Sources of variation and mean values for flour constituents: total arabinoxylan, water-unextractable arabinoxylans, water-extractable arabinoxylans, protein, and ash.

	TAX[a]	WUAX[b]	WEAX[c]	Protein[d]	Ash[d]
Whole model R^2	0.90	0.89	0.95	0.99	0.93
Flour blend F-value	67	60	2 ns	595	486
Grain lot F-value	14	13	29	121	8
Interaction F-value	2 ns[e]	2 ns	10	5	1 ns
Flour blend[f]					
Straight grade	1.22	0.83	0.39a	8.55	0.43
Patent	1.09	0.69	0.40a	8.07	0.35
LSD	0.09	0.10	0.05	0.31	0.02

[a]Total arabinoxylans; calculated as mg/g xylose equivalents relative to flour, 14% mb.
[b]Water-unextractable arabinoxylans; calculated as mg/g xylose equivalents relative to flour, 14% mb.
[c]Water-extractable arabinoxylans; calculated as mg/g xylose equivalents relative to flour, 14% mb.
[d]Protein (N × 5.7) and ash expressed as per cent of flour, 14% mb.
[e]ns, not significant at $P < 0.01$.
[f]Mean values expressed as a per cent; values followed by the same letter are not statistically different at $P < 0.01$.

Table 2–Sources of variation and mean values for end-use quality: water viscosity, peroxide-peroxidase viscosity, starch damage, cookie diameter, and cake volume.

	Water viscosity[a]	POx viscosity[b]	Starch damage[c]	Cookie diameter	Cake volume
Whole model R^2	0.90	0.98	0.88	0.96	0.88
Flour blend F-value	75	190	30	105	17
Grain lot F-value	15	67	10	20	17
Interaction F-value	2 ns[d]	12	3	–	–
Flour blend[e]					
Straight grade	13.5	10.3	3.62	9.3	1249
Patent	12.8	9.4	3.29	9.5	1283
LSD	0.5	0.8	0.32	0.1	32

[a]Water viscosity bostwick consistometer values.
[b]Peroxide-peroxidase viscosity bostwick consistometer values.
[c]Percent starch damage expressed on an "as is" moisture basis.
[d]ns, not significant at $P < 0.01$.
[e]Mean values expressed in cm for water viscosity, POx viscosity, and cookie diameter; cc for cake volume. All mean values significantly different at $P < 0.01$.

smaller cookie diameters and smaller cake volumes than patent flours (Table 2).

Mean values of TAX, WUAX, WEAX, protein, ash, water viscosity, POx viscosity, and starch damage of patent flours for each varietal grain lot are summarized in Table 3; straight grade flours are summarized in Table 4. Mean separation was performed using Tukey's procedure with a more conservative α set at $P = 0.01$. Mean separation was not performed for cookie diameter and cake volume because those measurements were not replicated. TAX, WUAX, and WEAX contents for soft white wheat varietal grain lot flours were similar to those previously reported for straight grade flour (Hong and others 1989; Saulnier and others 1995; Finnie and others 2006).

Patent flours of most grain lots contained similar concentrations of arabinoxylans, protein, ash, and starch damage, as well as similar viscosity measurements. For arabinoxylan fractions, TAX varied among grain lots 2-fold from 0.74% (Cara 2009) to 1.40% (Xerpha 2010), WUAX varied among grain lots nearly 4-fold from 0.24% (Cara 2009) to 0.93% (Stephens 2010c), and WEAX varied nearly 2-fold from 0.28% (Stephens 2008c) to 0.59% (Xerpha 2010). Protein content of patent flours varied among grain lots at 7.03% (Xerpha 2010) to 9.47% (Bitterroot 2008), whereas ash varied from 0.26% (Bruneau 2010) to 0.38% (Cataldo 2009). Starch damage ranged from 2.2% (Eltan 2010) to 4.4% (Xerpha 2010); a 2-fold difference among grain lots. For the 2 viscosity measurements, water viscosity had a relatively small range from 11.4 (ORCF102 2009) to 14.0 cm (Stephens 2010c

and 2008a), whereas POx viscosity had larger differences among grain lots, from the smallest flow distance of 1.5 cm for Xerpha 2010, to the largest flow distance of 11.3 cm for Stephens 2010b and Cara 2010. After Xerpha 2010, the next most viscous grain lot (smallest flow distance) was ORCF102 2009 at 6.9 cm.

Straight grade flours of the varietal grain lots contained similar distributions of arabinoxylan fractions, protein, ash, and starch damage compared to patent flours (although these constituents were higher due to the inclusion of 5 more mill streams in the straight grade flour blend). The viscosity measurements for straight grade flours were also similar (though generally less viscous) compared to the viscosity measurements for patent flours. TAX contents ranged among grain lots from 0.89% (Stephens 2009b) to 1.56% (Xerpha 2010), WUAX from 0.42% (Cara 2009) to 1.06% (Xerpha 2010), and WEAX from 0.26% (Eltan 2009) to 0.60% (Eltan 2010). Similar to patent flours there was approximately a 2-fold difference between the highest and lowest concentrations of WEAX and approximately a 3-fold difference among grain lots for WUAX content. However, unlike patent flours, there was less than a 2-fold difference among straight grade flours for TAX content. Protein content varied among straight grade flours from 7.40% (Xerpha 2010) to 10.17% (Bitterroot 2008), whereas ash content varied from 0.33% (Bruneau 2010) to 0.53% (Cataldo 2010). Starch damage for straight grade flours varied between 2.3% (Eltan 2010) and 4.48% (Stephens 2009c). For the viscosity measurements, water viscosity ranged from 12.0 (Eltan 2009 and

Table 3 –Total arabinoxylans, water-unextractable arabinoxylans, water-extractable arabinoxylans, protein, ash, water viscosity, peroxide-peroxidase viscosity, and starch damage of patent flour grain lots.[a]

	TAX (%)[b]	WUAX (%)[c]	WEAX (%)[d]	Protein (%)[e]	Ash (%)	Water viscosity (cm)	POx viscosity (cm)	Starch[f] damage (%)[f]
Xerpha 2010	1.40a	0.81a–e	0.59a	7.03l	0.33ab	12.1a–e	1.5h	4.4a
ORCF102 2008	1.29ab	0.88ab	0.41ab	8.21d–g	0.37a	11.6de	8.6d–f	3.1a–f
Stephens 2010c	1.28ab	0.93a	0.35g–k	7.40j–l	0.34ab	14.0a	11.0a	4.3a
Skiles 2008	1.25a–c	0.81a–e	0.44c–g	8.76bc	0.36ab	12.1a–e	8.8d–f	2.8a–f
Skiles 2010	1.23a–c	0.73a–e	0.50a–e	7.75g–k	0.35ab	12.6a–e	9.4b–e	4.0a–c
Eltan 2010	1.22a–c	0.71a–e	0.51a–d	7.88e–i	0.32ab	12.7a–e	9.9a–d	2.2f
Eltan 2008	1.18a–c	0.72a–e	0.46c–f	8.15d–g	0.34ab	11.8c–d	9.5b–e	2.7b–f
Stephens 2010a	1.17a–c	0.86a–d	0.31i–k	7.52i–k	0.37a	13.7ab	11.1a	3.4a–f
Cataldo 2010	1.17a–c	0.81a–e	0.36f–k	7.89e–i	0.38a	13.5a–d	10.6ab	3.7a–f
Stephens 2008a	1.16a–c	0.87a–c	0.29jk	7.80g–k	0.38a	14.0a	10.0a–d	3.6a–f
Bruneau 2010	1.10a–d	0.71a–e	0.39f–j	7.95e–i	0.26b	12.3a–e	10.6ab	2.7b–f
Bitterroot 2008	1.10a–d	0.79a–e	0.31jk	9.47a	0.36ab	12.6a–e	8.9c–f	2.4ef
Skiles 2009	1.09a–d	0.77a–e	0.32i–k	8.50cd	0.35ab	11.6de	7.7fg	3.3a–f
Stephens 2008b	1.09a–d	0.79a–e	0.30jk	7.85e–j	0.37a	13.0a–e	10.0a–d	3.2a–f
ORCF103 2010	1.08a–d	0.63a–f	0.45c–f	8.04e–h	0.37a	12.2a–e	10.8ab	3.8a–e
ORCF102 2009	1.05a–d	0.47d–f	0.58a–b	8.21d–g	0.35ab	11.4e	6.9g	3.3a–f
Stephens 2010b	1.04a–d	0.66a–e	0.38f–j	7.34kl	0.34ab	13.6a–e	11.3a	4.2ab
Cara 2010	1.04a–d	0.73a–e	0.31i–k	7.65h–k	0.33ab	13.8ab	11.3a	2.4d–f
Stephens 2008c	1.04a–d	0.76a–e	0.28k	7.80f–k	0.37a	13.0a–e	10.0a–d	3.1a–f
Stephens 2009a	1.03a–d	0.69a–e	0.34h–k	8.30de	0.30ab	12.5a–e	8.7d–f	3.7a–f
Eltan 2009	1.02b–d	0.60a–f	0.42d–h	8.17d–g	0.34ab	12.5a–e	8.3e–g	3.9a–e
Louise 2008	1.01b–d	0.67a–e	0.34h–k	8.06d–h	0.34ab	13.6a–c	9.5b–e	2.6c–f
Cataldo 2009	0.97b–d	0.55a–f	0.42d–h	8.85bc	0.38a	11.9b–e	9.9a–d	3.1a–f
Stephens 2009b	0.97b–d	0.48c–f	0.49b–e	8.23d–f	0.34ab	13.6a–c	9.5b–e	3.3a–f
Stephens 2009c	0.95b–d	0.41ef	0.54a–c	8.26de	0.34ab	12.9a–e	10.0a–d	4.0a–d
Cara 2008	0.93b–d	0.63a–f	0.30jk	8.99b	0.35ab	13.6a–c	10.3a–c	3.0a–f
Bitterroot 2009	0.88cd	0.53b–f	0.35g–k	7.93e–i	0.35ab	11.6de	8.8d–f	2.9a–f
Cara 2009	0.74d	0.24f	0.50a–d	8.20d–g	0.36ab	13.7ab	10.6ab	3.2a–f
LSD	0.16	0.17	0.04	0.20	0.05	0.8	0.6	0.7

[a]Values in columns followed by the same letter are not significantly different ($P < 0.01$).
[b]Total arabinoxylans; calculated as mg/g xylose equivalents relative to flour, 14% mb.
[c]Water-unextractable arabinoxylans; calculated as mg/g xylose equivalents relative to flour, 14% mb.
[d]Water-extractable arabinoxylans; calculated as mg/g xylose equivalents relative to flour, 14% mb.
[e]Protein (N $\times$ 5.7); 14% mb.
[f]Percent starch damage expressed on an "as is" basis.

ORCF102 2009) to 14.9 cm (Cara 2010), whereas POx viscosity ranged from 7.8 (Xerpha 2010) to 11.9 cm (Stephens 2010c).

Correlation coefficients were also calculated for end-use quality data (cookie diameter and cake volume) and arabinoxylan fractions, protein, ash, starch damage, and viscosity measurements to determine the relationship of flour constituents and viscosity measurements on end-use quality. However (and somewhat surprisingly), no strong, significant correlations were found (data not shown). Cookie diameter should have been strongly correlated with protein content, WEAX content, and starch damage (Donelson 1988; Gaines and others 1988; Gaines 1990; Kaldy and others 1993; Hoseney and Rogers 1994; Miller and Hoseney 1997; Donelson and Gaines 1998; Bettge and Morris 2000, 2007; Barrera and others 2007; Pareyt and Delcour 2008).

Variation in the concentration of constituents (arabinoxylans, protein, and ash) and oxidative cross-linking potential of flour blends (straight grade and patent) is primarily the result of mill stream selection for those flour blends. Flour blend was a greater source of variation than varietal grain lot for all response variables except WEAX. Straight grade flours (approximately 75% extraction rate) contained significantly more TAX, WUAX, ash, and protein than patent flours (approximately 60% extraction rate) as a direct result of mill stream blending since straight grade flours included all 10 Miag mill streams, whereas the patent flours contained only 5 of the highest purity (low ash) mill streams (Table 1). The cumulative extraction curves of Ramseyer and others (2011a) support these results in that a 60% extraction rate from a Miag pilot mill would produce a flour blend with lower concentrations of arabinoxylans and ash compared to a 75% extraction rate.

The viscosity measurements were significantly different for straight grade compared with patent flours. Patent flours were more viscous than straight grade flours for both viscosity measurements. In addition, the absolute difference between water and POx viscosity was greater for patent flours than for straight grade flours. Therefore, patent flours are usually more likely to form oxidative cross-links than straight grade flours. The oxidative cross-linking potential of patent flours is likely due to the fact that the mill streams utilized in the formulation (1st and 2nd Break, 1st and 2nd Middlings, and 1st Middlings redust) were those that are more likely to form oxidative cross-links (Ramseyer and others 2011b). However, straight grade flours also contain these same mill streams with high oxidative cross-linking potential (1st and 2nd Break, 1st and 2nd Middlings, and 1st Middlings redust) in addition to 5 other mill streams (3rd Break, Grader, and 3rd, 4th, and 5th Middlings). Nevertheless, straight grade flours produced significantly less viscous measurements compared to patent flours. This may indicate that the additional mill streams in straight grade flours (3rd Break, Grader, and 3rd, 4th, and 5th Middlings; encompassing approximately 15% extraction rate) have a deleterious or inhibitory effect on oxidative cross-linking potential.

It is also interesting to note that while patent flours were more viscous and more likely to form oxidative cross-links, they produced larger diameter cookies and greater cake volumes than straight grade flours. Since the WEAX content, on average,

Table 4–Total arabinoxylans, water-unextractable arabinoxylans, water-extractable arabinoxylans, protein, ash, water viscosity, peroxide-peroxidase viscosity, and starch damage of straight grade flour grain lots.[a]

	TAX (%)[b]	WUAX (%)[c]	WEAX (%)[d]	Protein (%)[e]	Ash (%)	Water viscosity (cm)	POx viscosity (cm)	Starch damage (%)[f]
Xerpha 2010	1.56a	1.06a	0.50a–d	7.40i	0.41b	12.5cd	7.8h	4.1a–d
ORCF102 2008	1.46ab	1.04ab	0.43b–h	8.44c–e	0.46ab	12.8a–d	9.4e–h	3.9a–d
Eltan 2010	1.44a–c	0.84a–d	0.60a	8.16d–h	0.42b	13.3a–d	10.0b–g	2.3e
ORCF103 2010	1.43a–c	0.98ab	0.45a–g	8.63b–d	0.43b	12.9a–d	10.5a–f	3.2b–e
Skiles 2010	1.40a–d	0.98ab	0.42b–h	8.30c–g	0.42b	12.9a–d	10.4a–f	3.5a–e
Stephens 2010a	1.36a–e	0.99ab	0.37c–h	7.84f–i	0.42b	14.5a–c	11.1a–e	3.7a–e
Eltan 2008	1.36a–e	0.88a–d	0.48a–e	9.11b	0.41bc	13.6a–d	9.9c–g	3.4a–e
Stephens 2010c	1.36a–e	1.03ab	0.33e–h	7.75hi	0.44b	14.6a–c	11.9a	4.4a–c
Stephens 2010b	1.35a–e	0.97ab	0.37c–d	7.76g–i	0.41bc	14.5a–c	11.6a–c	3.6a–e
Bruneau 2010	1.33a–f	0.91a–d	0.42b–h	8.28c–h	0.33c	13.4a–d	10.5a–f	3.1b–e
Cara 2010	1.31a–g	0.94a–c	0.37c–h	8.25c–h	0.42b	14.9a	11.6a–c	3.3a–e
Skiles 2008	1.31a–g	0.83a–d	0.48a–f	9.79a	0.44b	12.6b–d	9.6d–g	3.5a–e
Stephens 2008a	1.30a–g	1.01ab	0.29gh	8.36c–f	0.47ab	14.6a–c	11.8ab	4.1a–d
Bitterroot 2008	1.28a–g	0.97ab	0.31f–h	10.17a	0.45ab	13.0a–d	9.4e–h	3.9a–e
Louise 2008	1.28a–g	0.91a–d	0.37c–h	8.50c–e	0.43b	14.4a–c	9.6d–g	3.3a–e
Cataldo 2010	1.27a–g	0.96a–c	0.31e–h	8.56c–e	0.53a	14.4a–c	10.9a–f	2.9c–e
Stephens 2008c	1.26a–g	0.97ab	0.29gh	8.08e–h	0.46ab	14.8ab	11.3a–d	3.8a–e
Stephens 2008b	1.25a–g	0.93a–c	0.32f–h	8.16d–h	0.45ab	14.5a–c	11.6a–c	3.8a–e
ORCF102 2009	1.08b–g	0.74a–d	0.34d–h	8.66b–d	0.43b	12.0d	8.3gh	4.4a–c
Cara 2008	1.08b–g	0.78a–d	0.30gh	10.03a	0.44b	14.6a–c	11.3a–d	2.6de
Bitterroot 2009	1.04b–g	0.63a–d	0.41d–h	8.28c–h	0.44b	12.9a–d	9.8d–g	4.0a–d
Skiles 2009	1.03c–g	0.46cd	0.57ab	8.75bc	0.44b	12.5cd	9.6d–g	3.4a–e
Eltan 2009	0.97d–g	0.71a–d	0.26h	8.50c–e	0.39bc	12.0d	9.3f–h	3.5a–e
Stephens 2009a	0.97d–g	0.55b–d	0.42b–h	8.75bc	0.43b	13.1a–d	10.3a–f	4.4a–c
Cara 2009	0.94e–g	0.42d	0.52a–c	8.44c–e	0.42b	14.1a–d	11.1a–e	3.1b–e
Stephens 2009c	0.92fg	0.44d	0.48a–f	8.71bc	0.41bc	13.5a–d	10.3a–f	4.8a
Cataldo 2009	0.91fg	0.57a–d	0.34d–h	9.11b	0.46ab	12.5cd	10.1a–f	3.5a–e
Stephens 2009b	0.89g	0.59a–d	0.30gh	8.69b–d	0.41b	12.5cd	10.3a–f	4.5ab
LSD	0.18	0.21	0.07	0.23	0.04	0.9	0.8	0.6

[a]Values in columns followed by the same letter are not significantly different ($P < 0.01$).
[b]Total arabinoxylans; calculated as mg/g xylose equivalents relative to flour, 14% mb.
[c]Water-unextractable arabinoxylans; calculated as mg/g xylose equivalents relative to flour, 14% mb.
[d]Water-extractable arabinoxylans; calculated as mg/g xylose equivalents relative to flour, 14% mb.
[e]Protein (N × 5.7); 14% mb.
[f]Per cent starch damage expressed on an "as is" basis.

was not significantly different between straight grade flours and patent flours, the differences in cookie diameter may be partially attributed to differences in oxidative cross-linking of protein polymers. The findings of Bettge and Morris (2007) support this assertion in that cookie diameter was highly correlated with the enhanced oxidative cross-linking potential of protein when WEAX was hydrolyzed with a xylanase in flour slurries ($r = -0.76$). Therefore, differences in cookie diameter for straight grade and patent flours may be partially due to the oxidative cross-linking potential of protein. Alternatively, straight grade flours contained significantly more WUAX than patent flours. WUAX are known to bind up to 10 times their own weight in water (Jelaca and Hlynka 1971); this characteristic would affect the distribution and availability of water in the cookie dough, thus affecting the solubilization of sucrose and the overall cookie diameter.

For Japanese sponge cakes, end-use quality is primarily attributed to starch characteristics (Nakamura and others 2010 and references therein). However, we theorize that the larger cake volumes of the patent flours may be partially due to the oxidative cross-linking potential of WEAX and protein. Since patent flours are comprised of mill streams with high oxidative cross-linking potential, the increase in viscosity may aid in retaining gases while reducing the settling of large starch and flour particles. However, further research into the effect of oxidative cross-linking on Japanese sponge cake quality is needed to either support or refute this theory.

It is interesting that no strong, significant correlations were found among cookie diameter or cake volume and arabinoxylan fraction, protein, ash, starch damage, or viscosity measurements. The relationship of arabinoxylan fraction, protein, starch damage, and viscosity measurements on cookie diameter has been well established (Donelson 1988; Gaines and others 1988; Gaines 1990; Kaldy and others 1993; Hoseney and Rogers 1994; Miller and Hoseney 1997; Donelson and Gaines 1998; Bettge and Morris 2000, 2007; Barrera and others 2007; Pareyt and Delcour 2008). The relationship between cake volume and viscosity has also been reported (Gaines and Donelson 1982). The lack of strong, significant correlations for end-use quality data and flour constituents/viscosity measurements here is likely due to the fact this study included only commercial varieties that are more or less acceptable to the milling and baking industries. All of the samples in the present study were included in the U.S. Wheat Associates Overseas Varietal Analysis Program and are classified as U.S. Soft White wheat, falling into the Soft White or White Club subclasses. Differences would become clearer if samples were included that represent a greater range of values than exist within commercially produced grain lots, that is, early generation varieties in cultivar development programs.

The significant ANOVA interaction between grain lot and flour blend for WEAX content resulted from the fact that some grain lots contained more or less WEAX content in straight grade flour than in patent flour. This "cross-over" may be due to milling characteristics of the varieties and the distribution of WEAX in the kernel. Generally, WEAX content increases as extraction rate increases (Ramseyer and others 2011a). Ramseyer and others (2011a) found a significant interaction among varieties and mill streams for WEAX content. While the interaction between varieties and mill streams for WEAX was not explored in great depth, it would indicate that certain varieties contained higher concentrations of WEAX in some mill streams and lower concentrations of WEAX in other mill streams, relative to the other mean responses of other varieties.

In conclusion, straight grade flours contained significantly more TAX, WUAX, ash, and protein content than patent flours. The 2 flour blends were not significantly different in terms of WEAX content but the interaction between flour blends and grain lots indicates that some grain lots produce low extraction flour blends with a higher concentration of WEAX. However, patent flours were more likely to form oxidative cross-links than straight grade flours; this result may be attributed to the functional characteristics of the individual mill streams that were selected for the 2 different flour blends. Patent flours produced larger cookie diameters and Japanese sponge cake volumes than straight grade flours. The differences in cookie diameter are likely attributed to differences in oxidative cross-linking potential of the protein in flour blends. More research is needed to determine the effect of oxidative cross-linking of WEAX and protein polymers on Japanese sponge cake volumes.

Acknowledgments

References

AACC Intl. 2008. Method 46-30, 10-52, 76-31. Approved methods of the American Association of Cereal Chemists International. 10th ed. St. Paul, Minn.: AACC.

Ambalamaatil S, Lukow OM, Hatcher DW, Dexter JE, Malcolmson LJ, Watts BM. 2002. Milling and quality evaluation of Canadian hard white spring wheats. Cereal Foods World 47:319–27.

Barrera GN, Perez GT, Riboota PD, Leon AE. 2007. Influence of damaged starch on cookie and break-making quality. Eur Food Res Tech 225:1–7.

Bettge AD, Morris CF. 2000. Relationship among grain hardness, pentosan fractions, and end-use quality of wheat. Cereal Chem 77:241–7.

Bettge AD, Morris CF. 2007. Oxidative gelation measurement and influence on soft wheat batter viscosity and end-use quality. Cereal Chem 84:237–42.

Chaudhary VK, Yamazaki WT, Gould WA. 1981. Relation of cultivar and flour particle size distribution to cake volume. Cereal Chem 58:314–7.

Donelson JR. 1988. The contribution of high-protein fractions from cake and cookie flours to baking performance. Cereal Chem 65:389–91.

Donelson JR, Gaines CS. 1998. Starch-water relationships in the sugar-snap cookie dough system. Cereal Chem 75:660–4.

Douglas SG. 1981. A rapid method for the determination of pentosans in wheat flour. Food Chem 7:139–45.

Finnie SM, Bettge AD, Morris CF. 2006. Influence of cultivar and environment on water-soluble and water-insoluble arabinoxylans in soft wheat. Cereal Chem 83:617–23.

Gaines CS. 1985. Association among soft wheat flour particle size, protein content, chlorine response, kernel hardness, milling quality, white layer cake volume, and sugar-snap cookie spread. Cereal Chem 62:290–2.

Gaines CS. 1990. Influence of chemical and physical modification of soft wheat protein on sugar-snap cookie dough consistency, cookie size, and hardness. Cereal Chem 67:73–7.

Gaines CS, Donelson JR. 1982. Cake batter viscosity and expansion upon heating. Cereal Chem 59:237–40.

Gaines CS, Donelson JR, Finney PL. 1988. Effect of damaged starch, chlorine gas, flour particle size, and dough holding time and temperature on cookie dough handling properties and cookie size. Cereal Chem 65:384–9.

Hatcher DW, Symons SJ. 2000. Assessment of oriental noodle appearance as a function of flour refinement and noodle type by image analysis. Cereal Chem 77:181–6.

Hong BH, Rubenthaler GL, Allen RE. 1989. Wheat pentosans: I. Cultivar variation and relationship to kernel hardness. Cereal Chem 66:369–73.

Hoseney RC, Rogers DE. 1994. Mechanism of sugar functionality in cookies. In: Faridi H, editor. The science of cookie and cracker production. St. Paul, Minn.: AACC.

Jelaca SL, Hlynca I. 1971. Water binding capacity of wheat flour crude pentosans and their relation to mixing of dough. Cereal Chem 48:211–22.

Kaldy MS, Kereliuk GR, Kozub GC. 1993. Influence of gluten components and flour lipids on soft white wheat quality. Cereal Chem 70:77–80.

Kruger JE, Anderson MA, Dexter JE. 1994. Effect of flour refinement on raw Cantonese noodle color and texture. Cereal Chem 71:177–82.

Miller RA, Hoseney RC. 1997. Factors in hard wheat flour responsible for reduced cookie spread. Cereal Chem 74:330–6.

Morita SI, Ito T, Hirano S. 1974. A gel-forming polysaccharide containing ferulic acid in protein-free form present in aqueous extract of wheat flour. Int J Biochem 5:201–5.

Morris CF, Rose SP. 1996. Wheat. In: Henry RJ, Kettlewell PS, editors. Cereal grain quality. 1st ed. London: Chapman and Hall.

Nagao S, Imai S, Sato T, Kaneko Y, Otsubo H. 1976. Quality characteristics of soft wheat and their use in Japan: I. Methods of assessing wheat suitability for Japanese produces. Cereal Chem 53:988–97.

Nakamura K, Taniguchi Y, Taira M, Ito H. 2010. Prediction of specific Japanese sponge cake volume using pasting properties of flour. Cereal Chem 87:505–10.

Neukom H, Markwalder HU. 1978. Oxidative gelation of wheat flour pentosans: a new way of cross-linking polymers. Cereal Foods World 23:374–6.

Niño-Medina G, Carcajal-Millán E, Rascon-Chu A, Marquez-Escalante JA, Guerrero V, Salas-Muñoz E. 2010. Feruloylated arabinoxylans and arabinoxylan gels: structure, sources and applications. Phytochem Rev 9:111–20.

Nishio Z, Oikawa H, Haneda T, Seki M, Ito M, Tabiki T, Tamauchi H, Muira H. 2009. Influence of amylose content on cookie and sponge cake quality and solvent retention capacities in wheat flour. Cereal Chem 86:313–8.

Oudgenoeg G, Hilhorst R, Piersma SR, Boeriu CG, Gruppen H, Hessing M, Voragen AGJ, Laane C. 2001. Peroxidase-mediated cross-linking of a tyrosine-containing peptide with ferulic acid. J Agric Food Chem 49:2503–10.

Pareyt B, Delcour JA. 2008. The role of wheat flour constituents, sugar, and fat in low moisture cereal based products: a review on sugar-snap cookies. Crit Rev Food Sci Nutr 48:824–39.

Ramseyer DD, Bettge AD, Morris CF. 2011a. Distribution of total, water-unextractable and water-extractable arabinoxylans in wheat flour mill streams. Cereal Chem 88:209–16.

Ramseyer DD, Bettge AD, Morris CF. 2011b. Endogenous and enhanced oxidative cross-linking in wheat flour mill streams. Cereal Chem 88:217–22.

Saulnier L, Peneau N, Thibault JF. 1995. Variability in grain extract viscosity and water-soluble arabinoxylan content in wheat. J Cereal Sci 22:259–64.

Vinkx CJA, Van Nieuwenhove CG, Delcour JA. 1991. Physicochemical and functional properties of rye nonstarch polysaccharides: III. Oxidative gelation of a fraction containing water-soluble pentosans and proteins. Cereal Chem 68:617–22.

Wang M, Hamer RJ, von Vliet T, Oudgenoeg G. 2002. Interaction of water extractable pentosans with gluten protein: effect of dough properties and gluten quality. J Cereal Sci 36:25–37.

Ye Y, Zhang Y, Yan J, Zhang Y, He Z, Huang S, Quail KJ. 2009. Effects of flour extraction rate, added water, and salt on color and texture of Chinese white noodles. Cereal Chem 86:477–85.